EDDY CURRENT CRACK SIGNALS IN SMALL DIAMETER TUBING

Steven Ross and William Lord

Department of Electrical Engineering and Computer Engineering
Iowa State University
Ames, Iowa 50011

INTRODUCTION

Eddy current nondestructive testing methods are effective for the detection of cracks in conducting materials. However, to insure that the detection is reliable an accurate reference standard must be used in instrument calibration. Electrical-discharge-machined (EDM) notches have been used as a reference standard for fatigue cracks (1, 2). However, many researchers argue that an EDM notch gives a larger signal than an actual fatigue crack (3, 4) and thus cannot be used as an equivalent model. Much of the previous research on this topic was done with a probe over a flat block. This paper discusses the case of a probe inside a tube with cracks growing from the outer diameter. The focus of this investigation is to compare actual fatigue crack signals with signals from EDM notches and a finite element simulation.

This research is part of a NASA project developing an automated nondestructive testing system for use in the Space Shuttle Main Engine (SSME) heat exchanger unit. The SSME heat exchanger tubing is shown in Fig. 1 (5). The unit consists of small diameter stainless steel tubing which carries liquid oxygen through the engine chamber.

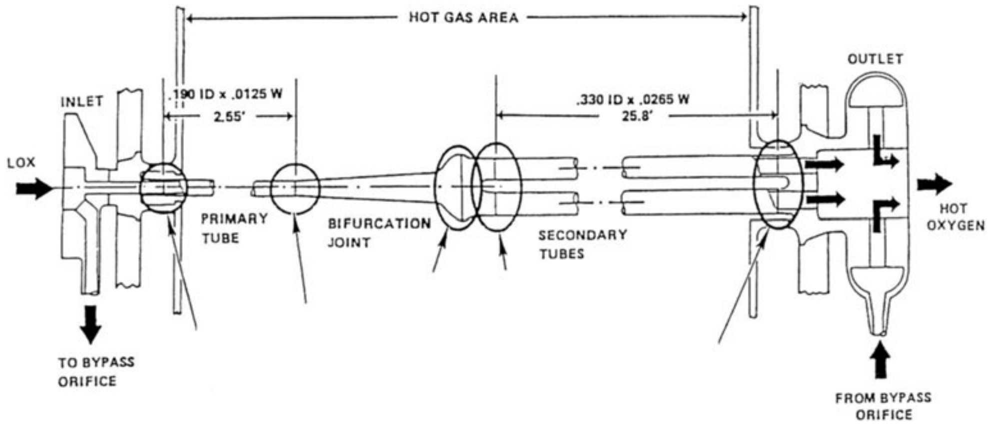

Figure 1 Tubing in SSME heat exchanger

Review of Progress in Quantitative Nondestructive Evaluation, Vol. 11
Edited by D.O. Thompson and D.E. Chimenti, Plenum Press, New York, 1992

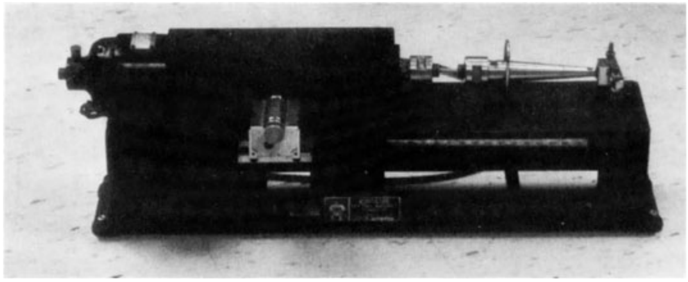

Figure 2 Fatigue machine

PROCEDURE

In order to simulate the larger tube in the heat exchanger unit stainless steel tubing with an O.D. of 7/16" and a 0.035" wall thickness was used in the study. A 600 KHz differential probe was used for defect detection.

The fatigue cracks were grown with a Krause fatigue machine. The fatigue machine is shown in Fig. 2. The tube specimen was cut to four inches length and placed in the machine. The tube was then end loaded with between 160 and 200 lbs. Then the entire system was rotated slowly at approximately 200 rpm. This placed the tube in constant tension and compression causing the tube to produce heat. The system was then allowed to cool and the process was repeated. Eventually a small transverse crack appeared which could then be grown larger. Difficulty was encountered in predicting where the crack would appear, the sample was often deformed in the collets and the process took several hours.

Next the EDM notches were prepared. This is a process of metal removal by electrical discharge. The EDM notches were cut in a transverse direction from the axis of the tube. The width of the notches at the widest point was 0.006". EDM notches can be produced with widths as small as one or two mils but special rigid graphite blades are needed. The main disadvantage of the EDM notches is that their width is larger than that of corresponding fatigue cracks.

The finite element method was used to model the differential probe interaction with fatigue cracks. The principle of this method is to solve the diffusion equation through the minimization of an energy functional (6, 7). This particular finite element code was 2-D axisymmetric in nature. The region of interest is discritized with triangular elements and the magnetic vector potential is solved for at each node. A diagram of the mesh used is shown in Fig. 3. Each element was 0.002" wide in the area traversed by the probe. Smaller crack widths can be studied but this drastically increases the number of elements resulting in large CPU times.

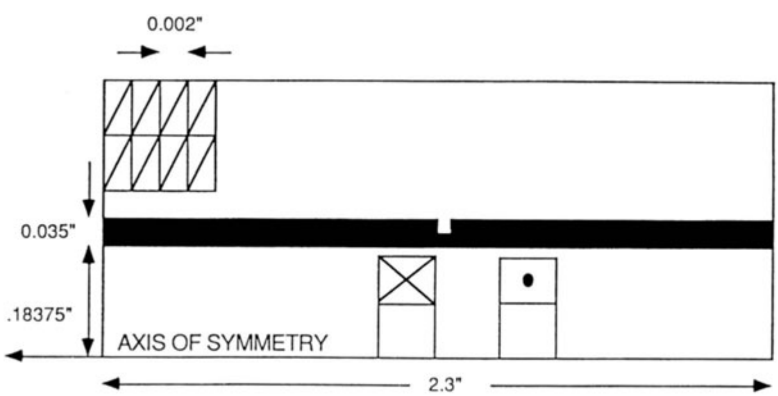

Figure 3 Finite element mesh

RESULTS

Figure 4 and Fig. 5 show the impedance plane trajectories (IPT) of growing fatigue cracks. The distances are measures of crack length around the circumference. The IPTs are somewhat distorted because of tube deformation in the fatigue process. From the figures we can see that as the crack length increases the IPT grows in magnitude but does not vary in phase. The crack depth was not measured during the experiment but we do know that eventually the crack becomes 'through-wall' with no phase change appearing in the IPT.

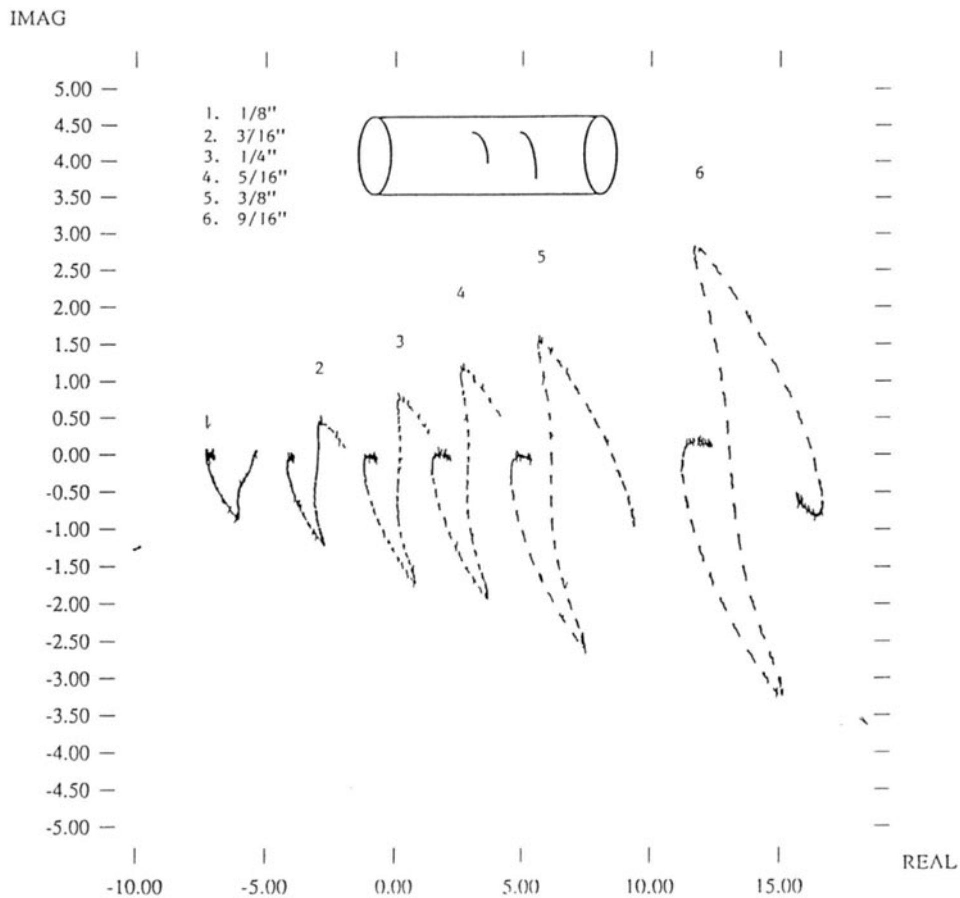

Figure 4 Impedance plane trajectories of fatigue crack growth

For the case of EDM notches of increasing depth again the distance is a measurement of length around the circumference. The notches are straight through, transverse to the axis and eventually penetrate the tube wall. We can see in Fig. 6 that the IPT for the EDM notch also grows without any change in phase. EDM notch signals are compared with fatigue crack signals in Fig. 7. From the figure we can see that the EDM notch gives a very comparable signal with the fatigue crack. Not only does the phase compare well but the amplitudes are nearly equal.

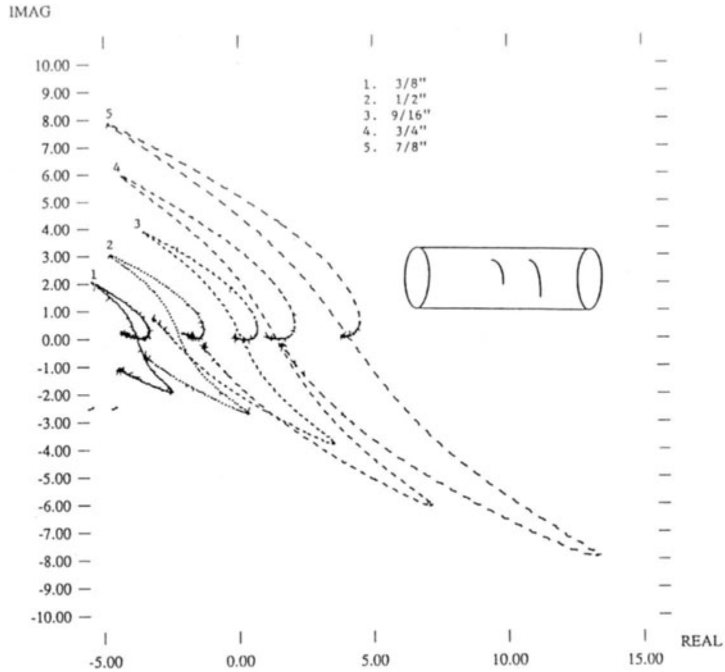

Figure 5 Impedance plane trajectories of fatigue crack growth

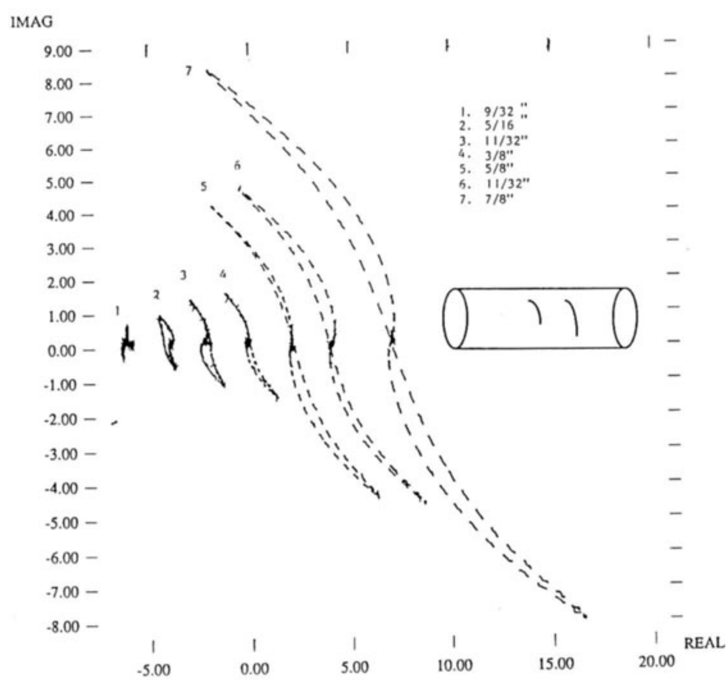

Figure 6 EDM crack growth

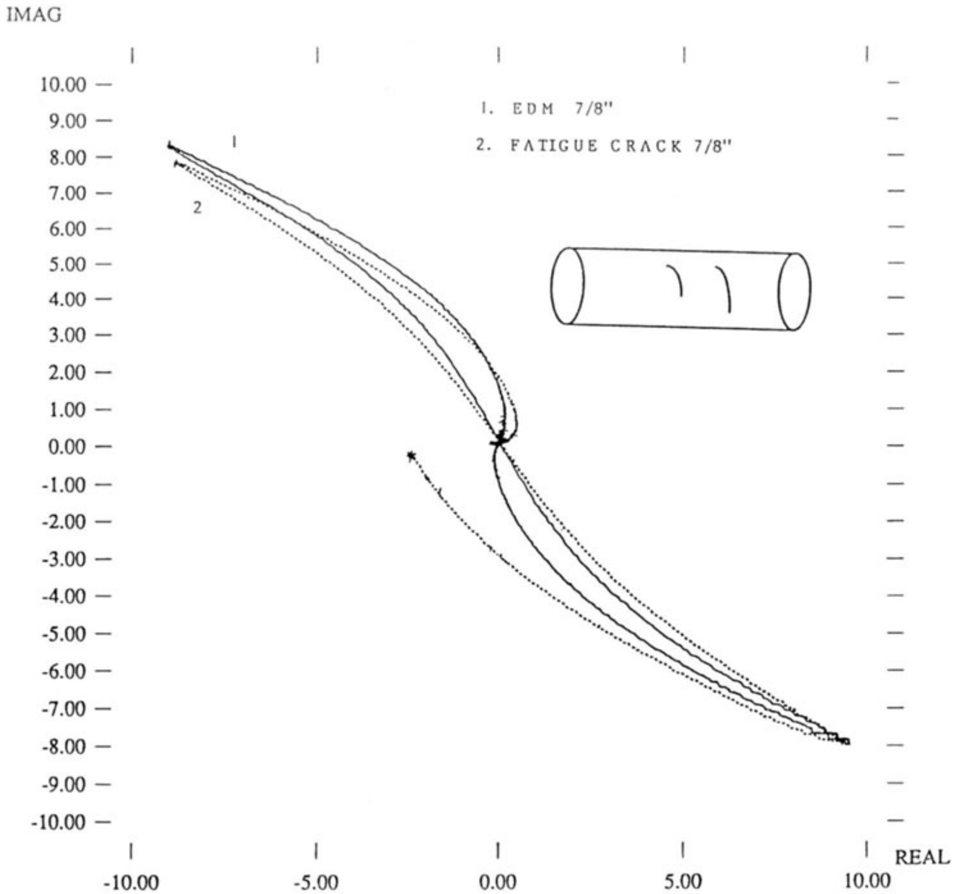

Figure 7 Fatigue crack vs. EDM notches

Results of the finite element comparison are given in Fig. 8. In Fig. 8a. a crack with constant width and varying depth is modelled. From the figure we can see that the phase is changing as the depth of the cracks changes. This phenomena did not occur with actual fatigue crack growth. A crack with constant depth and varying width is modelled in Fig. 8b. In this case the IPT has constant phase and increasing magnitude as occurred with the fatigue cracks. Finally, axisymmetric cracks of 80 percent through wall depth are compared with actual fatigue cracks. Figure 9 shows that the phase is equivalent and, by varying the width of the modelled crack, the magnitudes of the IPTs also compare well.

CONCLUSIONS

From the results we can see that for tubular geometries the transverse fatigue cracks grew in constant phase. Signals from EDM notches do compare well with the fatigue cracks in stainless steel tubing. The finite element code predictions also compare well with the actual fatigue crack signals. It should be noted that although the fatigue cracks were not completely axisymmetric it was possible to model them with an axisymmetric code because the differential probe averages the entire signal over its circumference. Future work will make use of a 3-D finite element model and measurement of fatigue crack depth as the cracks are grown.

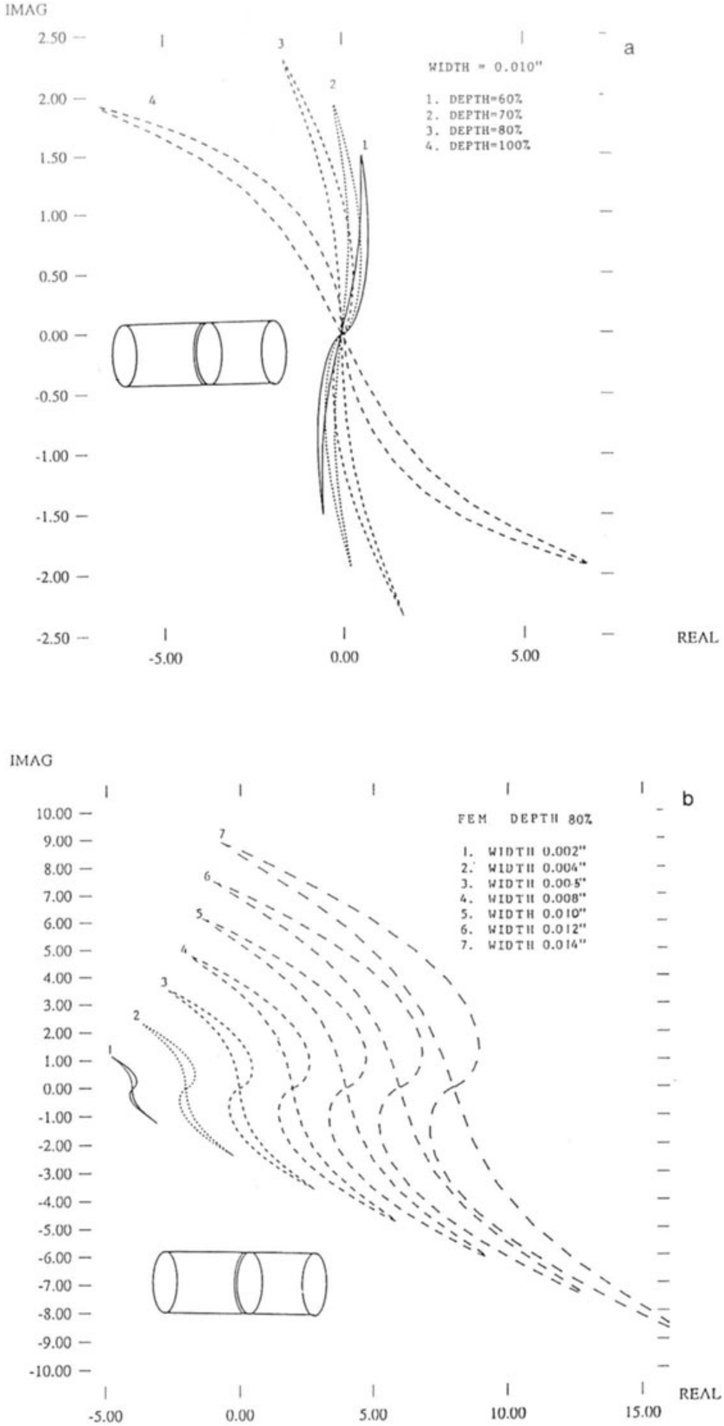

Figure 8 (a) Crack with constant width and varying depth
(b) Crack with constant depth and varying width

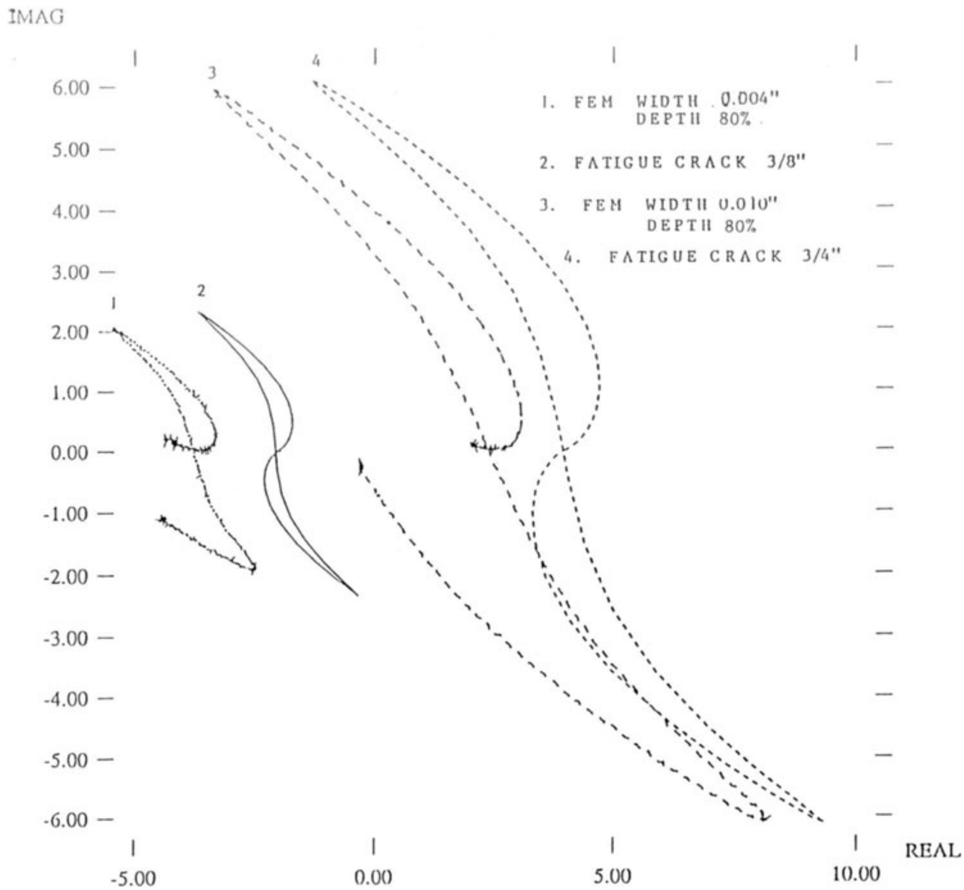

Figure 9 A comparison of FEM vs. actual fatigue cracks

REFERENCES

1. W. L. Zemberry, Mat. Eval., Vol. 28, p. 81 (1970).
2. D. A. Hagemaier and J. A. Register, Mat. Eval., Vol. 48, p. 50 (1990).
3. W. D. Rummel, J. C. Moulder, N. Nakagawa, Review of Progress in Quantitative NDE , edited by D. O. Thompson and D. E. Chimenti (Plenum Press, New York, 1990), Vol. 10A, p. 277.
4. J. Hartman, Review of Progress in Quantitative NDE, opsit , (Plenum Press, New York, 1990), Vol. 10A, p. 285.
5. H. Quong, SSME Heat Exchanger Coil Weld Nondestructive Inspection Review, BC 87-32, (1987).
6. R. Palanisamy and W. Lord, IEEE Trans. MAG, Vol. 15, No. 6, p. 1479, (1979).
7. W. Lord, IEEE Trans. MAG, Vol. 19, No. 6, p. 2437 (1983).